Validation Of Visual Threat Recognition And Avoidance Training Through Analogical Transfer

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Summary

The Visual Threat Recognition and Avoidance Trainer (VTRAT) system addresses the need for realistic training that enables forces to respond quickly and operate effectively during threat engagements. This initiative combines state-of-the-art visual, interactive simulations with intelligent tutoring methodologies to train the visual scanners. VTRAT is an automated virtual intelligent instructional training aid, designed to introduce or refresh scanners on visual recognition of threats and on their duties during a threat engagement. This paper describes two studies that employ a backward transfer procedure for validating the training effectiveness of VTRAT. In experiment 1, 34 Air Force aircrew personnel were tested at Air Force Special Operations Command on their identification of surface-to-air missiles (SAMs). Several types of SAMs were simulated and presented to participants. Participants identified the model of SAM, and the accuracy of trajectory (whether or not the SAM would hit their simulated aircraft). Participants were assigned to either a novice group (no combat experience) or expert group (combat experience in either the Kosovo or Iraqi air campaigns). The experts outperformed the novices on all performance measures. In experiment 2, 39 aircraft scanners with the 19th Special Operations Squadron at Hurlbert Field, FL completed VTRAT training upon return from deployment in Afghanistan. There was a significant positive correlation between number of antiaircraft artillery (AAA) threats observed in theater and AAA threat recognition in VTRAT. Together these two studies provide evidence supporting the validity of VTRAT training for recognizing and avoiding visual threats. Additionally, survey results indicated that scanners rated the VTRAT visuals to be highly realistic and VTRAT training to be valuable compared to previous training methods.

Introduction

Air Force Special Operations Command (AFSOC) aircraft scanners (crewmembers) have the primary duty to identify antiaircraft threats, direct the pilot and crew in performance of evasive maneuvers, and deploy countermeasures during an antiaircraft threat engagement. Survival of slow-moving aircraft during enemy engagements with non-radar antiaircraft weapons hinges on the rapid detection and responses of visual scanners. Once enemies engage using optically guided antiaircraft artillery or infrared surface-to-air missiles (IR-SAM), scanners must detect the threat and respond with appropriate verbal calls dispensing countermeasures within a matter of seconds.

Traditionally aircrew members have received little or no training in detecting threats. Operating procedures are rarely practiced. It is impractical to train detection skills by firing live rounds or actual SAMs at aircraft during training flights. Moreover, while procedures for handling threat engagements are written down, they are not practiced often enough to become routine. In fact, many crewmembers may not be completely familiar with the specified procedures. Consequently, when facing threats in actual operations, crewmembers may not have the ability to respond in an accurate and timely manner.

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In 1998 the Warfighter Training Research Division of the Air Force Research Laboratory (AFRL/HEAI), began development of a synthetic trainer for the 19th Special Operations Squadron (SOS). This training system, called the Visual Threat Recognition and Avoidance Trainer (VTRAT), was designed to train loadmasters in AC-130 Gunships to rapidly detect and execute countermeasures for various simulated threats (Figure 1). Basic system functionality, dictated by the prescribed training methodology, includes: (a) a view of the threat environment from the perspective of the scanner in the airframe, (b) accurate visualization of threat characteristics, (c) a high-fidelity interface for scanner communications and countermeasures, and d) dynamic feedback indicating timeliness, accuracy, and effectiveness of response.

Figure 1. Visual Threat Recognition and Avoidance Trainer (VTRAT).

The system combines state-of-the-art visual, interactive simulations with intelligent tutoring methodologies to provide an adaptive and efficient solution for training visual scanners. VTRAT decomposes the skill of threat detection and avoidance into subskills and focuses on each subskill. First the visual characteristics of various threats are displayed and discussed. Then learners are trained to recognize and distinguish enemy launches that pose an actual threat to the aircraft from those that do not. After learners achieve a level of proficiency on recognizing threats, the avoidance procedures are discussed and illustrated. Following this discussion, learners have an opportunity to practice these avoidance procedures. In this way the skill is built up from declarative knowledge into automated behavior.

Due to the success of the initial project, the VTRAT system was expanded to include all visual scanners on the AC-130 (Gunship), MC-130/U (Talon I), MC130/H (Talon II), MC130/P (Shadow), and the MH-53 (Pavelow). This expanded project required coding for each additional crew position viewpoint. In addition, each airframe was programmed to fly slightly different profiles and each was programmed for slightly different avoidance tactics. Moreover, the threat systems being modeled were certified on visual characteristics of antiaircraft weaponry, including missile fly-out, AAA rate-of-fire, trajectory, speed, etc., by the Air Force Information Warfare Center as valid for training purposes.

The goal of this research project is to validate the training effectiveness of the VTRAT system for training visual scanners to recognize threats and execute avoidance procedures. The most optimal way to test the validity is to measure the transfer from the training system to actual operations or actual exercise with live fire. Cost, risk, and logistics render this method of validation infeasible.

An alternative approach to validation is to measure the task transfer from experts to the training system. Knowledge and skill transfer is not unidirectional. Expertise gained during training transfers to the relevant task, but expertise gained on the relevant task will also transfer back to training. The critical assumption is that the fidelity of the training to the task is sufficient to promote transfer. Thus the representation of the necessary task knowledge must be sufficiently analogous to the task to promote transfer (e.g., see Singley & Anderson, 1989; Gick & Holyoak, 1980, 1983; Holyoak, 1984).

Measuring the extent to which skills and expertise acquired in field operations transfer back to training systems provides a training validation metric. This procedure is called backward transfer. The amount of backward transfer should reflect the fidelity of the training system (Wightman & Lintern, 1985). Goettl and Shute (1996) demonstrated how backward transfer could be used to improve the efficiency of part-task training. The backward transfer procedure is depicted in Figure 2. In their study Goettl and Shute trained one group using whol-task training and another group using a series of part tasks. Following training both groups performed the whole task and then completed the part tasks. We compared the performance of the whole-task group on the part tasks to the initial performance of the part-task group on the part tasks. Any part tasks that the whole-task group performed better (i.e., showed backward transfer) were identified as critical tasks and were included in a modified part-task condition. The modified part-task condition resulted in overall better training than whole-task training.

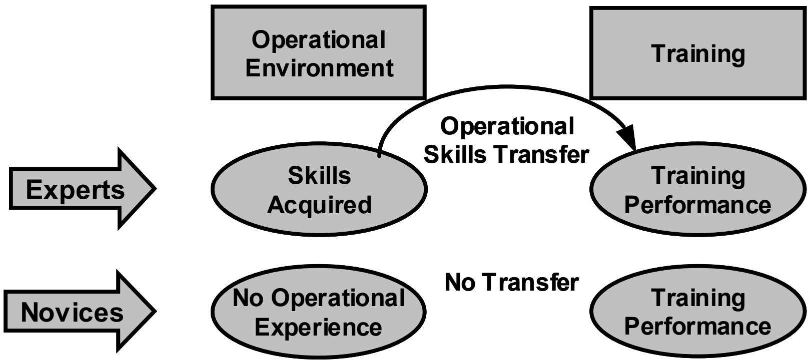

Figure 2. Backward Transfer approach to training validation.

In the present study backward transfer will be used to measure the training validity of the VTRAT system. The approach was similar to that employed by Goettl, Ashworth, and Chaiken (in press). Modular Control Equipment (MCE) operators conduct the same functions as Airborne Warning and Control System (AWACS) weapons directors except from ground-based stations. These duties and responsibilities include: control friendly fighter aircraft, monitor friendly fuel consumption, refuel friendly assets, monitor hostile aircraft, protect ground assets, deploy fighters against hostiles when necessary, collaborate with other operators, pass control of aircraft back and forth between sectors of the airspace. Goettl et al. had Air Force Modular Control Equipment (MCE) operators perform a synthetic team task configured to simulate the duties and responsibilities of a team of AWACS weapons directors. Operators performed the task under two different scenarios and with two different interfaces. Goettl et al. compared the operators' performance during acquisition and transfer phases with the performance of novices. They found that operators performed better during acquisition and transfer phases of the task. While novices showed dramatic performance decrements when the interface was changed, experienced operators showed no decrement at all. This clearly indicates that the operators had a richer knowledge of the AWACS task and were able to transfer that knowledge to the training task regardless of changes in the scenario and interface.

The present study presents two backward transfer experiments to validate the VTRAT system for training effectiveness. In Experiment 1 we compare the VTRAT performance of self-identified threat experts against the performance of threat novices. The prediction is that experts will perform better on VTRAT. In Experiment 2 the performance on VTRAT of aircrews will be correlated with the amount of threat experience during recent operations including Kosovo and Afghanistan. A positive correlation reflects positive transfer and will provide evidence of training efficacy. Aircraft scanners from the 19th SOS at Hurlbert Field, FL. completed VTRAT training upon return from deployment in Afghanistan. Correlations were calculated between experience with real-world threat engagements and VTRAT performance. In addition, we administered surveys to assess judgments of simulation realism and training effectiveness.

Experiment 1

Method

Subjects. Thirty-four Air Force Aircrew personnel were tested at AFSOC at Hurlbert Field, FL. Participants were assigned to either a Novice (n = 25) or Expert (n = 9) group based on their real-world military combat experience. The Novice group were Special Operations trainees, none of whom had combat experience. The Expert group had C-130 experience during either Operation Allied Force (Kosovo) or Operation Desert Storm (Iraq), and had engaged actual enemy air defenses.

Apparatus and Materials. The VTRAT is a state-of-the-art training system that incorporates high-fidelity graphics and voice recognition technologies (Figure 1). Five software components collaborate to provide VTRAT functionality: an Image Generator (IG), an Interaction Server (IS), a Threat System (TS), an Aircraft Host (AH), and a Situated Adaptive Learning Technology (SALT) component. These components were implemented using commercial-off-the-shelf (COTS) and government-off-the-shelf (GOTS) development tools on COTS hardware.

The SALT component allows both the automated instruction and an instructor to control the simulated environment. The instructor uses SALT's graphical user interface (GUI) to control the simulated threat environment and monitor student performance. The GUI allows the instructor to modify numerous simulation dynamics such as scanner viewpoint, aircraft altitude, airspeed. Currently, VTRAT contains courses to train threat recognition and avoidance for all duty positions requiring scanner training in the Gunship, Talon-I, Talon-II, Shadow, and MH-53J weapon systems.

The IG, TS, and AH form the heart of the 3-D visual simulation. These components run on an SGI Onyx2-IR2 and are certified High Level Architecture (HLA) compliant. The aircraft host models a C-130 or MH-53J, on a mission flight path, dynamically changing altitude, airspeed, and flight path as requested through scanner communications, the instructor's GUI, or automated instruction. The TS models a variety of AAA and SAMs. It dynamically generates threats based on instructional objectives that dictate threat placement and targeting parameters.

The student views the appropriate crew position perspective of the simulated threat environment on a high-resolution 67" display system. The student wears a headset, with a microphone attached for purposes of voice recognition, and holds a communication control and a flares countermeasures control. Both controls are from the actual aircraft, modified to communicate with VTRAT through a PC game port. The IS (running Windows 2000 on a 500 MHz PC) delivers instructional text as synthesized speech output, and monitors scanner communications. The speech recognition software provides speaker-independent, continuous speech recognition, with no training requirements.

Procedure. In the first phase trainees were required to discriminate between the three SAMs until they reached an accuracy criterion. They also had to state whether or not the SAM was accurate or inaccurate (would or would not hit the C-130). There was no time pressure. Both the identity and accuracy of the SAMs were evenly distributed across trials. To successfully complete this phase trainees had to complete at least 20 trials, and 9 of the last 10 trials had to be correct for both identity and accuracy of SAM. Trainee's verbal responses were processed by the speech recognition system, which then supplied accuracy feedback. The second phase was identical to the first except that it was conducted under time pressure. The trainees had to meet criterion first within an 8-second time window, then a 6-second window, and finally within a 4-second window. Thus not responding within the time window became an additional type of error.

Results

Reported here are the data from the final phase of training. Independent samples t-tests revealed four main effects (Table 1). Due to unequal group size, homogeneity of variance was not assumed. There was a significant difference in Proportion Correct, $\underline{t}$ (12.58) = 2.49, $\underline{p} < .05$, indicating that Experts ($\underline{M}$ = .78) had a higher proportion correct than Novices ($\underline{M}$ = .68). There was a significant difference in total number of SAMs shown, $\underline{t}$ (26.69) = -2.22, $\underline{p} < .05$,

indicating that Novices (M = 32.28) required more trials to reach criterion than Experts (M = 24.33). There was a significant difference in the number of Time Outs, $t\ (17.02) = -2.05$, $p = .05$, indicating that Novices (M = 5.44) were more likely to miss the time window for responses than were Experts (M = 2.89). Finally, there was a significant difference in the overall minutes to finish training, $t\ (31.09) = -2.00$, $p = .05$, indicating that Novices took longer (M = 16.56) than Experts (M = 12.59).

Dependent Variable	Novice	Expert	Significance
Proportion Correct	.68	.78	< .05
Total Number Shown	32.28	24.33	< .05
Time Outs	5.44	2.89	< .05
Total Minutes to Criterion	16.56	12.59	< .05

Table 1. Significant VTRAT outcome measures with means.

Discussion

The superior performance of the Expert group suggests that experts are in fact transferring their extant knowledge from their real-world SAM experience to the VTRAT training task. It can then be inferred that there is sufficient fidelity between VTRAT and its real-world counterpart to make VTRAT a viable training device.

It is often the case that training systems cannot be validated through their real-world counterparts. However, this does not preclude other methods of validation. Measuring the transfer from experts' extant knowledge back to the training system is an affordable and theoretically appropriate method of validation in such circumstances.

Considering the high costs in human life, materiel, and mission effectiveness associated with ineffective training systems, there is ample reason why Air Force training systems such as VTRAT should always be validated.

Experiment 2

Method

Participants. Participants were 39 Aircrew members from the 19^{th} and 20th Air Force SOSs. Participants ranged in age from 18 to 30 and had a high school diploma or Graduate Equivalency Degree (GED). Participants included pilots, co-pilots, flight engineers, loadmasters, scanners, and gunners from five different airframes: gunship, Talon I, Talon II, shadow, and MH-53. All participants were recruited by AFSOC personnel and participated voluntarily.

Equipment. The equipment used in Experiment 2 is the same as was used in Experiment 1.

VTRAT Task. In this Experiment participants completed two drill lessons of VTRAT. In one drill participants had to detect and initiate avoidance tactics for different IR SAM threats. The threats modeled in the system were three MANPAD systems including the SA-7, SA-14, and SA-16. Participants had to make the appropriate call and deploy countermeasures within a specified length of time. The drill consisted of 20 trials. In the second drill, participants had to detect and initiate avoidance tactics for AAA threats. Participants were graded on each component of the avoidance call and whether they completed the call within a specified window. As part of the detection, participants had to determine whether the AAA threats were firing at the aircraft or not, and whether the maneuver they called was appropriate. Participants completed a minimum of 20 trials and had to get 9 of the last 10 to complete the drill. Five different AAA threats were modeled: 14.5 mm, 23-2mm, 23-4mm, 37mm, and 57mm.

Questionnaire. The questionnaire consisted of three parts. The first part of the survey assessed general mission experience as well as combat experience. Participants indicated number of flights and total flight hours in theatre. In

addition they were asked to indicate how many times they had observed SAM and AAA threats firing at them or other aircraft in theater.

The second part of the survey dealt with specific threats modeled in VTRAT. Participants were asked to indicate how often they had observed each of the different threats modeled in VTRAT and to rate the VTRAT simulations on different dimensions. Rating scales consisted of a 6-point Likert–type scale with anchors representing very inaccurate (1) and very accurate (6). Only those having seen the specific threats in theater were required to rate the simulations.

In the final section of the survey participants were asked to rate the quality of VTRAT training compared to previous training methods. Participants rated the quality of the discussion of the visuals, discussion of the tactics, and realism of the threats and scenarios. Ratings were made using a 6-point Likert-type scale with poor (1) and excellent (6) as the anchors. The aspects of VTRAT that were rated included (a) discussion of visual features of AAA threats, (b) discussion of visual features of IR-SAM threats, (c) discussion of avoidance tactics for AAA threats, (d) discussion of avoidance tactics for IR-SAM threats, (e) realism of AAA threats, and (f) realism of IR-SAM threats.

Procedure. The data reported here were collected at the 19th SOS in Hurlbert Field, FL. Participants signed in and were given a subject-matter expert (SME) number to maintain confidentiality. They were briefed on the goals and purposes of the study. Following these instructions, participants completed the IR-SAM recognition and avoidance drill. Next, participants completed the AAA threat avoidance drill. Finally, participants were asked to complete the questionnaire, were debriefed, and released.

Results

Of the 39 participants only 33 completed the drills. Due to computer errors, data from 3 participants were lost. Of the remaining 30 participants with performance data, there were 16 gunship crewmembers, 3 Talon crewmembers, 6 Shadow crewmembers, and 5 MH-53 crewmembers.

Performance and Experience. The primary goal of this study was to validate the accuracy of the simulation. The approach was to correlate accuracy of threat calls with amount of experience. If the visual characteristics of the threat simulations and flight simulation are accurate, there should be a significant positive correlation between performance on the threat calls and amount of experience. In the present study, experience was measured multiple ways: number of missions in theater, number of hours in theater, and number of times AAA or SAMs were seen fired upon self or others. On average, participants viewed AAA shot at themselves 3.67 time (SD = 6.12), AAA fired at others 3.07 times (SD = 3.859), SAMs shot at themselves 0.33 times (SD = 0.84), and SAMs fired at others 0.23 times (SD = 0.73).

Each of these measures was correlated with performance on threat. Table 2 shows the correlations between experience measures and accuracy of AAA and SAM threat calls and locations.

Experience	**AAA Threat**	**AAA Location**	**SAM Threat**	**SAM Location**
Total Missions	.155	.036	-.128	-.132
Total Hours	.057	-.276	.133	-.053
Threat at own ship	.116	.227	.109	-.042
Threat at other ships	.447*	.301	.184	-.102

Table 2. Correlations between VTRAT performance and threat experience: number of missions, number of mission hours, number of times viewed threat fired at own aircraft, and number of times viewed AAA fired at other aircraft (*p < .05).

As indicated in Table 2, in general, performance on AAA threat calls in VTRAT are positively correlated with experience. Moreover, correlations tend to be stronger for the experience metrics based on frequency of viewing actual threats in theater. In spite of this positive evidence, only the correlation between threat call and number of times viewed AAA fired at others reached statistical significance.

Correlations involving SAM performance and experience, as indicated in Table 2 were not as strong as correlations for AAA. This is likely due to a restriction of range problem. That is, very few participants had viewed actual SAM threats in theater. Additionally, performance on SAM threat calls were highly accurate ranging from 95% correct for shadow crews to 98 % correct for gunship crews. Nevertheless the correlations between threat call accuracy and the number of times SAMs had been viewed are positive.

Subjective Ratings of Training Value. An important metric in training is the perceived value of training. Participants were asked to compare the VTRAT training to previous training approaches on several dimensions. These dimensions included discussion of visuals and tactics for AAA and SAM threats, and realism of AAA and SAM threats. Table 3 shows the average ratings for several VTRAT dimensions.

VTRAT Dimension	Average Rating
Discussion of AAA Visuals	5.48
Discussion of SAM Visuals	5.46
Discussion of AAA Tactics	5.04
Discussion of SAM Tactics	5.35
Realism of AAA Threats	5.27
Realism of SAM Threats	5.24

Table 3. Average ratings of VTRAT quality metrics

As indicated in Table 3, overall the ratings of VTRAT were relatively high. On a 6-point scale where 6 is excellent, no rated aspect of VTRAT was rated below a 5.00. Compared to other training approaches that participants experienced, VTRAT was rated nearly excellent on all dimensions. The discussion of visuals showed the highest ratings followed by the discussion of SAM tactics, then realism of the threats. The aspect of VTRAT rated the lowest was the discussion of AAA tactics. This is not entirely surprising given that avoidance of AAA threats is more complex and based on perceptual judgments that are difficult to model on a 2-dimensional display.

Discussion

The data presented here support the conclusion that VTRAT provides valuable training experience to visual scanners. This evidence comes not only from the subjective ratings of visual scanners but from backward transfer analysis.

Perhaps the most important finding in this study is the strong positive correlation between experience and VTRAT performance. Accuracy of AAA threat calls was positively and significantly correlated with the number of times scanners had viewed AAA threats firing at other aircraft. This is the kind of backward transfer evidence that supports the validity of training. Those with more experience and familiarity with actual threats performed better on recognition

and avoidance drills. While in the current data, the strongest effects were shown for AAA performance, correlations between SAM threat d[illegible] and experience were positive for all experience measures except total missions.

The difference in backward transfer between AAA experience and SAM experience may reflect the relatively little experience participants had with SAM threats. Moreover, the experience with SAM engagements was not correlated to total number of missions (.116 and -.050 for SAMs at you and at others, respectively). For AAA experience the number of total missions was strongly correlated with number AAA threats viewed (.626 and .517 for AAA fired at you and at others, respectively). Again the weak correlations likely reflect restriction of range problems. Very few participants had seen SAMs at the time of testing (M = .33).

Finally, we obtained strong positive results from the subjective ratings of the training value. All rated aspects of VTRAT training received an average rating of 5 or more on a scale where 6 represented excellent value. These data reflect the general response that VTRAT developers have received from AFSOC personnel. In fact, the system was so highly valued that AFSOC personnel created compact disks of VTRAT simulations and passed them around to aircrews during the Afghanistan operations. In summary, the data presented demonstrate and confirm the validity of VTRAT simulations and drills for training the recognition and avoidance of visual threats.

General Discussion

These two experiments provide converging evidence that the VTRAT system is effective for training the recognition and avoidance of threats. Both experiments used a backward transfer approach to training validation. This technique measures the amount of transfer from the real-world task to the training system. This approach assumes that if the training system captures important task dimensions, then experts will perform better on the training system than will novices. In Experiment 1 backward transfer was measured by comparing VTRAT performance of operators with combat experience to performance of operators without combat experience. In that experiment experts performed better on all performance metrics of IR-SAM detection in the VTRAT. This finding supports the conclusion that experts were able to transfer combat experience to the training environment.

In Experiment 2, experience was measured more directly through a survey measuring specific experience perceiving AAA and SAM threats. In this experiment, the extent of real-world experience viewing AAA was positively correlated with VTRAT performance in detecting AAA threats. The finding that operators with greater experience viewing actual AAA threats performed better than those with less experience supports the conclusion that VTRAT captures important dimensions of the threat detection task.

It is difficult to validate the effectiveness of simulators designed for combat training. The most logical approach for measuring transfer from the training to the operational task is not practical. Measuring transfer from the training system to a very high-fidelity simulation can be expensive and is limited to the validity of the simulation. The backward transfer approach provides a practical inexpensive way of validating the effectiveness of military training systems. The present paper demonstrates two approaches to backward transfer to the validation of a training system and can serve as a model for future validation efforts.

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